

CONTROL OF A PHOTSENSITIVE CELL

Background Of The Invention

5 1. Field of the Invention

The present invention relates to the control of a photosensitive cell made in monolithic form of an image sensor intended to be used in shooting devices such as, for example, shooting cameras, camcorders, digital microscopes, or digital cameras. More specifically, the present invention relates to a photosensitive cell based on
10 semiconductors.

2. Discussion of the Related Art

Fig. 1 schematically shows the circuit of a photosensitive cell of a photosensitive cell array of an image sensor. With each photosensitive cell of the array are associated a
15 precharge device and a read device. The precharge device is formed of an N-channel MOS transistor M_1 , interposed between a supply rail V_{dd} and a read node S . The gate of precharge transistor M_1 receives a precharge control signal RST . The read device is formed of the series connection of two N-channel MOS transistors, M_2 , M_3 . The drain of first read transistor M_2 is connected to supply rail V_{dd} . The source of second read
20 transistor M_3 is connected to input terminal P of an electronic processing circuit (not shown). The gate of first read transistor M_2 is connected to read node S . The gate of second read transistor M_3 is capable of receiving a read signal R_D . The photosensitive cell comprises a charge storage diode D_1 having its anode connected to a reference supply rail or circuit ground GND and its cathode directly connected to node S . The
25 photosensitive diode comprises a photodiode D_2 having its anode connected to reference supply rail GND and its cathode connected to node S via an N-channel charge transfer MOS transistor M_4 . The gate of charge transfer transistor M_4 is capable of receiving a charge transfer control signal T . Generally, signals R_D , RST , and T are provided by control circuits not shown in Fig. 1 and can be provided to all the photosensitive cells of
30 a same row of the cell array.

Fig. 2 shows an example of a timing diagram of signals R_D , RST , T , and of voltage V_{RD} at node S of the circuit of Fig. 1 for a read cycle of the photosensitive cell of

Fig. 1. Signals R_D , RST , and T are binary signals varying between high and low levels that can be different for each of the signals.

Between two read cycles of the photosensitive cell, signal T is low. Transfer transistor M_4 is thus off. The lighting causes the forming and the storage of charges at the level of photodiode D_2 . Further, signal RST is high. Precharge transistor M_1 is thus on. Voltage V_{RD} is then substantially equal to voltage V_{DD} .

At a time t_0 , the array row containing the photosensitive cell to be read is selected by setting, to the high level, signal R_D . The precharge of read node S is interrupted by setting at time t_1 signal RST to the low state, thus turning off precharge transistor M_1 . Voltage V_{RD} at read node S is then set to a precharge level V_{RST} which can be lower than voltage V_{DD} due to a coupling with precharge transistor M_1 . Precharge level V_{RST} is generally disturbed by noise essentially originating from the thermal noise of the channel of precharge transistor M_1 . This noise is sampled and maintained on charge storage diode D_1 upon turning-off of precharge transistor M_1 . Precharge level V_{RST} is then stored outside of the photosensitive cell via read transistors M_2 , M_3 .

At time t_2 , signal T is set to the high state. Transfer transistor M_4 is then on, which enables transfer of the charges stored in photodiode D_2 to read node S . Photodiode D_2 is designed so that all the charges stored therein are transferred to read node S . Voltage V_{RD} then decreases to reach a wanted signal level V_{RD} . Once the charge transfer has been performed, signal T is set at time t_3 to the low level, thus enabling isolating photodiode D_2 again and resuming a cycle of charge forming and storage due to the lighting. Desired signal level V_{RD} is then read via read transistors M_2 , M_3 . Like precharge level V_{RST} , desired signal level V_{RD} is especially disturbed by the thermal noise of the channel of precharge transistor M_1 , which has been sampled and maintained on charge storage diode D_1 . The subtraction of signals V_{RD} and V_{RST} by the processing circuit enables suppressing the noise of precharge transistor M_1 by a double correlated sampling. Once the reading is over, signal RST is set to the high state at time t_4 to precharge read node S again. Finally, at time t_6 , signal R_D is set to the low state to deselect the photosensitive cell.

It is possible for diode D_1 not to be formed by a specific component. The function of storing the charges originating from photodiode D_2 is then ensured by the apparent capacitance at read node S which is formed of the capacitances of the sources of

transistors M_1 and M_4 , of the input capacitance of transistor M_2 , as well as of all the stray capacitances present at node S.

Fig. 3 illustrates, in a partial simplified cross-section view, an implementation in monolithic form of the assembly of photodiode D_2 and of transfer transistor M_4 of Fig. 1. These elements are formed in a same active area of a lightly-doped semiconductor substrate 1 of a first conductivity type, for example, type P (P^-). This substrate for example corresponds to an epitaxial layer on a silicon wafer which forms reference supply rail GND. The active area is delimited by field insulation areas 2, for example, made of silicon oxide (SiO_2), and corresponds to a well 3 of the same conductivity type as underlying substrate 1, but more heavily doped. Above the surface of well 3 is formed an insulated gate structure 4 possibly provided with lateral spacers. On either side of gate 4, at the surface of well 3, are source and drain regions 5 and 6 of the opposite conductive type, for example, N. Drain region 6, to the right of gate 4, is heavily doped (N^+). Source region 5 is formed on a much larger surface area than drain region 6 and forms with underlying substrate 3 the junction of photodiode D_2 . Gate 4 and drain 6 form one piece with metallizations (not shown) which enable putting these regions in contact respectively with transfer control signal T and the gate of transistor M_2 (node S). The structure is completed by heavily-doped P-type regions 8 and 9 (P^+). Regions 8 and 9, underlying areas 2, are connected to the reference or ground voltage via well 3 and substrate 1. Photodiode D_2 is of the so-called completely depleted type and comprises, at the surface of its source 5, a P-type region 7, shallow and more heavily doped (P^+) than well 3. Region 7 is in lateral (vertical) contact with region 8. It is thus permanently maintained at the reference voltage level.

Fig. 4 schematically illustrates the voltage levels of the different regions of Fig. 2. The curve in strip-dot lines illustrates the system state just after time t_2 . Heavily-doped P-type regions 7, 8, and 9 are permanently maintained at the reference or ground voltage, for example, 0 V. Region 5 of photodiode D_2 , completely charged, is at a voltage V_{DC} . Transistor M_4 is on. Channel region 3 of transistor M_4 is at a voltage V_{TR} . Region 6 corresponding to node S is at precharge level V_{RST} . Between times t_2 and t_3 , the charges accumulated in region 5 are transferred to region 6. The curve in full line illustrates the system state just after time t_3 . The charges stored in photodiode D_2 being completely transferred to node S, photodiode D_2 reaches a so-called depletion quiescent level V_D set

by the sole characteristics of photodiode D_2 . Transfer transistor M_4 being off, channel region 3 is at 0 V. Region 6 is at the level of wanted signal V_{RD} . Region 5 of photodiode D_2 then forms an empty potential well which refills according to the photodiode lighting.

Generally, the high level of transfer control signal T applied to the gate of transfer transistor M_4 is such that the voltage in channel region 3 of transistor M_4 is intermediary between depletion level V_D , and wanted signal level V_{RD} , in such voltage conditions.

For denser and denser technologies with photosensitive cells of small dimensions and lower and lower control signals, it becomes difficult to ensure a good charge transfer from photodiode D_2 to read node S.

To improve the charge transfer, it is possible to increase the high level of signal T applied on the gate of transfer transistor M_4 to increase the intensity of the electric field enabling the charge flow. However, if the level of the channel of transfer transistor M_4 becomes relatively too high with respect to supply voltage V_{DD} , charges may be stored during the charge transfer in channel region 3 of transfer transistor M_4 due to the capacitive character of transistor M_4 . Charges can thus be sent back to photodiode D_2 at the falling edge of signal T from the high level to the low level at time t_3 . This may translate as an error on the measured wanted signal level V_{RD} and result in a so-called "trailing" effect upon successive readings of a photosensitive cell, due to the reading of residual charges of the previous image upon reading of the next image.

Summary Of The Invention

The present invention provides a method and a device for controlling a photosensitive cell enabling ensuring complete transfer of the charges from the photodiode to the read node.

To achieve these and other objects, the present invention provides a device for controlling a photosensitive cell comprising a photodiode adapted to discharging into a read node via a MOS transfer transistor, said device being adapted to providing a signal for controlling the gate of the MOS transfer transistor to a first level for which the MOS transfer transistor is off or to a second level for which the MOS transfer transistor is on, comprising means for providing a transition control signal between the second level and the first level of determined average slope.

According to an embodiment of the present invention, the device comprises a MOS transistor of a first conductivity type connected to a voltage source at the second level and to a control line, said control line being connected to the gate of the transfer MOS transistor, and a MOS transistor of a second conductivity type connected to said control line and to a terminal of a constant current source, the other terminal of said
5 constant current source being connected to a voltage source at the first level.

According to an embodiment of the present invention, the device further comprises a constant current source arranged between the transistor of the first conductivity type and the voltage source at the second level.

10 According to an embodiment of the present invention, the gates of the transistors of the first and second conductivity types receive a binary signal.

According to an embodiment of the present invention, the control signal is simultaneously provided to the gates of the transfer transistors of several photosensitive cells.

15 The present invention also provides a method for controlling a photosensitive cell, comprising a photodiode adapted to discharging into a read node via a MOS transfer transistor, comprising providing to the gate of the MOS transfer transistor a control signal at a first level to turn off said transfer transistor or at a second level to turn on said transfer transistor, and comprising providing, upon transition from the second level to the
20 first level, a control signal of determined average slope.

According to an embodiment of the present invention, the control signal is a signal of non-zero finite slope between the second level and the first level.

According to an embodiment of the present invention, the control signal comprises an intermediary stage with a zero slope between the second level and the first
25 level.

According to an embodiment of the present invention, the duration of said transition of the control signal from the second level to the first level is greater than 50 ns.

The foregoing object, features, and advantages of the present invention will be
30 discussed in detail in the following non-limiting description of specific embodiments in connection with the accompanying drawings.

Brief Description Of The Drawings

Fig. 1, previously described, shows an electric diagram of a photosensitive cell;

Fig. 2, previously described, illustrates a timing diagram of characteristic voltages of the circuit of Fig. 1;

Fig. 3, previously described, shows a simplified partial cross-section view of a portion of the circuit of Fig. 1 made in monolithic form;

Fig. 4, previously described, schematically illustrates voltage levels in the structure of Fig. 3;

Fig. 5 shows a first embodiment of the last stage of a control circuit providing charge transfer control signal T;

Fig. 6 shows a timing diagram of voltages characteristic of the circuit of Fig. 1 controlled by the control circuit of Fig. 5;

Fig. 7 shows a second embodiment of the last stage of the control circuit; and

Fig. 8 shows a timing diagram of voltages characteristic of the circuit of Fig. 1 controlled by the control circuit of Fig. 7.

Detailed Description

The same elements have been referred to with the same reference numerals in the different drawings and, further, as usual in the representation of integrated circuits, Fig. 3 is not drawn to scale.

The present invention comprises providing a charge transfer control signal T having a determined average slope upon transition between the high level and the low level to enable complete transfer of the charges between photodiode D_2 and read node S.

Fig. 5 shows a first embodiment of the last stage of a control circuit providing charge transfer control signal T to the gate of transfer transistor M_4 . The control circuit may be connected to a line L connected to all the transfer transistor gates of the photosensitive cells of a same photosensitive cell row. The control circuit comprises a P-type MOS transistor M_5 having its drain connected to a high-level voltage source V_{TH} and having its source connected to line L. The control circuit comprises an N-type MOS transistor M_6 having its drain connected to line L and having its source connected to a terminal of a constant current source I providing a current of intensity I_d . The other terminal of constant current source I is connected to a low-level voltage source V_{TL} . The

gates of transistors M_5 , M_6 each receive a binary signal C provided by the preceding stage of the control circuit. According to an alternative of the present invention, the gates of transistors M_5 , M_6 are not connected and each receive a distinct control signal.

When signal C is low, transistor M_6 is off and transistor M_5 is on. Transfer control signal T is then at high level V_{TH} . When signal C switches high, transistor M_5 is off and transistor M_6 is on. Line L , as seen from the control circuit, exhibits an apparent capacitance C_L originating among others from the gates capacitances of the charge transfer transistors of the different photosensitive cells in the row. Current source I then causes a transition of constant slope of signal T from high level V_{TH} to low level V_{TL} . The duration of the transition between the high and low levels is given by the following relation:

$$T_d = C_L(V_{TH} - V_{TL})/I_d$$

The constant slope of transfer control signal T is adjusted to enable all the charges present under the gate of transfer transistor M_4 to flow towards read node S before the voltage of the channel of transfer transistor M_4 reaches the reference level, for example, 0 volt. The phenomenon of charges returning to photodiode D_2 is then suppressed. It is desired to obtain a maximum value of T_d of approximately $0.5 \mu s$ and preferably of approximately $0.2 \mu s$. For this purpose, one can choose V_{TH} equal to 3.5 V, V_{TL} equal to 0 V, and C_L equal to several picofarads.

Fig. 6 shows a timing diagram of signals R_D , RST , and T of the photosensitive cell of Fig. 1 receiving a transfer control signal T provided by the control circuit of Fig. 5. Duration T_d can be adjusted by intensity I_d of the current provided by current source I . Current source I may be formed in any known manner, for example, by a current mirror.

Fig. 7 shows a second embodiment of the last stage of the control circuit providing signal T . As compared to the circuit of Fig. 5, the circuit according to the second embodiment comprises a second constant current source I' providing a current of intensity I_d' and arranged between the drain of transistor M_5 and the source of high-level voltage V_{TH} . Second constant current source I' enables ensuring a transition at constant slope of a duration T_d' of signal T between low level V_{TL} and high level V_{TH} . Duration T_d' is given by a relation similar to the expression of duration T_d , in which the amount of current I_d is replaced by the amount of current I_d' provided by constant current source I' .

Preferably, current sources I , I' provide currents of the same value so that durations T_d and T_d' are equal. This enables obtaining symmetrical rising and falling edges of signal T and suppressing unwanted coupling effects which can appear with the control circuit of Fig. 5.

5 According to an alternative of the present invention, not shown, the control circuit may provide a transfer control signal T which exhibits upon switching from the high level to the low level one stage or several intermediary stages at constant intermediary levels between high and low levels V_{TH} and V_{TL} . The intermediary level and the duration of the stage are set to ensure a complete charge transfer from photodiode
10 D_2 to read node S . The intermediary level is such that the voltage of the channel of charge transfer transistor M_4 is smaller than V_D to leave time to the charges present under transistor M_4 to set off to read node S . A stage may also be provided upon transition of signal T from the low level to the high level.

 According to an alternative of the present invention, not shown, the control
15 circuit may provide a transfer control signal T which exhibits upon switching from the high level to the low level one or several portions at non-zero constant slope, it being possible to provide the portions at constant slope between the high level and an intermediary level between the high and low levels, between an intermediary level between the high and low levels and the low level, or between a first intermediary level
20 between the high and low levels and a second intermediary level between the high and low levels smaller than the first intermediary level.

 According to an alternative of the present invention, not shown, transfer control signal T may exhibit upon switching from the high level to the low level a succession of portions at non-zero constant slope or of portions at zero slope.

25 According to an alternative of the present invention, not shown, transfer control signal T may exhibit upon switching from the high level to the low level one or several portions at non-constant slope varying according to a determined law.

 According to another alternative of the present invention, two control circuits operating identically may be arranged at both ends of line L .

30 Of course, the present invention is likely to have various alterations, modifications, and improvement which will readily occur to those skilled in the art. In particular, the drain of second read MOS transistor M_3 may be connected to supply rail

Vdd, and the source of second transistor M_3 may be connected to the drain of first read transistor M_2 . The source of first read transistor M_2 is then connected to input terminal P of the processing circuit. The operation of such a photosensitive cell is similar to what has been described previously. Further, the present invention has been described in the context of a photosensitive cell in which four MOS transistors are associated with a photodiode. However, the present invention may apply to photosensitive cells in which some of the MOS transistors, especially read transistor M_2 and M_3 and precharge transistors M_1 , are put in common between several photodiodes. Further, in the present invention, some of said N-type transistors may be replaced with P-type transistors by accordingly modifying the associated gate control signals.

Such alterations, modifications, and improvements are intended to be part of this disclosure, and are intended to be within the spirit and the scope of the present invention. Accordingly, the foregoing description is by way of example only and is not intended to be limiting. The present invention is limited only as defined in the following claims and the equivalents thereto.

What is claimed is: